Engineer's Notebook

aids for the structural engineer's toolbox

How Full Can Concrete Trucks be when Driving on Slabs-on-Grade?

By Rafik R. Gerges, P.Eng, Ph.D., S.E., SECB, LEED AP, BSCP and Harsh K. Nisar, MSCE

Rafik R. Gerges is a Principal at HSA & Associates, Inc., La Mirada, California. Dr. Gerges can be reached at ***rgerges@hsaassociates.com****.*

Harsh K. Nisar is a Senior Structural Designer at HSA & Associates, Inc., La Mirada, California. He can be reached at ***harsh@hsaassociates.com****.*

In typical tilt-up construction, the slab-on-grade is the working surface for the lifespan of the building. Certain situations, such as otherwise inaccessible panel casting beds, demand the use of the slab as a path of access for construction vehicles like concrete trucks. These trucks, when full, can exert high loads and pose a risk to the slab's serviceability. An acceptable compromise involves filling the truck only partially when driving over the slab-on-grade. The extent to off-load the truck depends on various parameters including slab, soil, and vehicle properties.

For large-scale warehouses and distribution centers, tilt-up construction is the preferred option from a cast-and-schedule standpoint. These buildings tend to have multiple repeatable elements and connections, so all stages of a given project tend to roll at a brisk pace. Typically, once the footings are poured, the slab-on-grade is cast. The slab is used as a casting bed for wall panels, which form the shell of the building. Once the panels are poured, they are tilted up using cranes and placed into their positions around the building perimeter with temporary braces. The roof is erected and connected to the wall panels to complete the structure.

Most contractors plan the pouring of the wall panels in such a way that all the panels can be poured, albeit in stages, from outside the building. However, special conditions arise from time-to-time, limiting accessibility. The access to wall panel casts might be blocked due to a variety of reasons, such as closeness to the property line or unforgiving soil. In these cases, the slab is used as an access path to pour panels. The slab is typically designed for a uniform load, rack point load, and forklift load addressing service conditions. Such a design may not always accommodate a full concrete truck. Each concrete panel can require 30 cubic yards of concrete, depending on the building dimensions and project location. A panel pour of 500 cubic yards is not uncommon, for which multiple truckloads are required. Depending on the slab capacity to take this wheel load, a truck can be partially off-loaded to have minimal effect on the serviceability performance of the slab.

A balance between what the slab can support without visible cracking versus the number of trucks needed to complete a given pour is required.

American Concrete Institute Approach

The slab-on-grade is modeled as a plate supported on a continuous area spring. The plate is acted upon by a load distributed over a small area representing a wheel. The design goal is to keep the slab uncracked under the action of wheel loads

Most recognized methods are based on Westergaard's solutions. These equations assume that the plate dimensions are sufficiently large to avoid edge effects due to the load. The critical location of the wheel for design is in the interior of a slab. To avoid the creation of any free edges under wheel loads, and to help against the effects of curling, sufficient smooth dowels should be provided at all edges and corners, which is the current practice. A factor of safety is employed against the modulus of rupture of concrete for additional assurance.

ACI 360R-10, *Guide to Design of Slabs-on-Grade*, suggests the following methods for determining the thickness of a concrete slab-on-grade under wheel loads.

i. Portland Cement Association Method (PCA): published by PCA in *Concrete Floors on Ground* (2001)
ii. Wire Reinforcement Institute Method (WRI): published by WRI in *Design Procedures for Industrial Slabs* (1973)

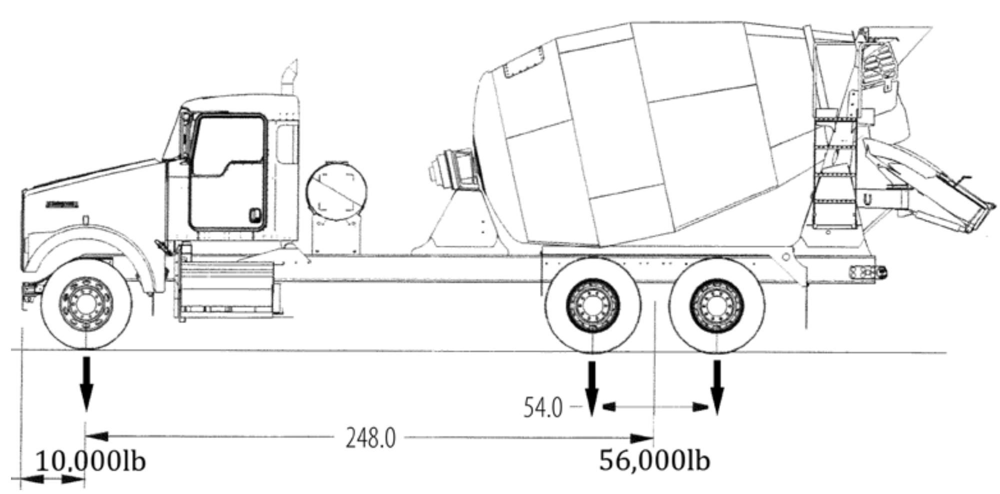

Figure 1. A typical concrete truck.

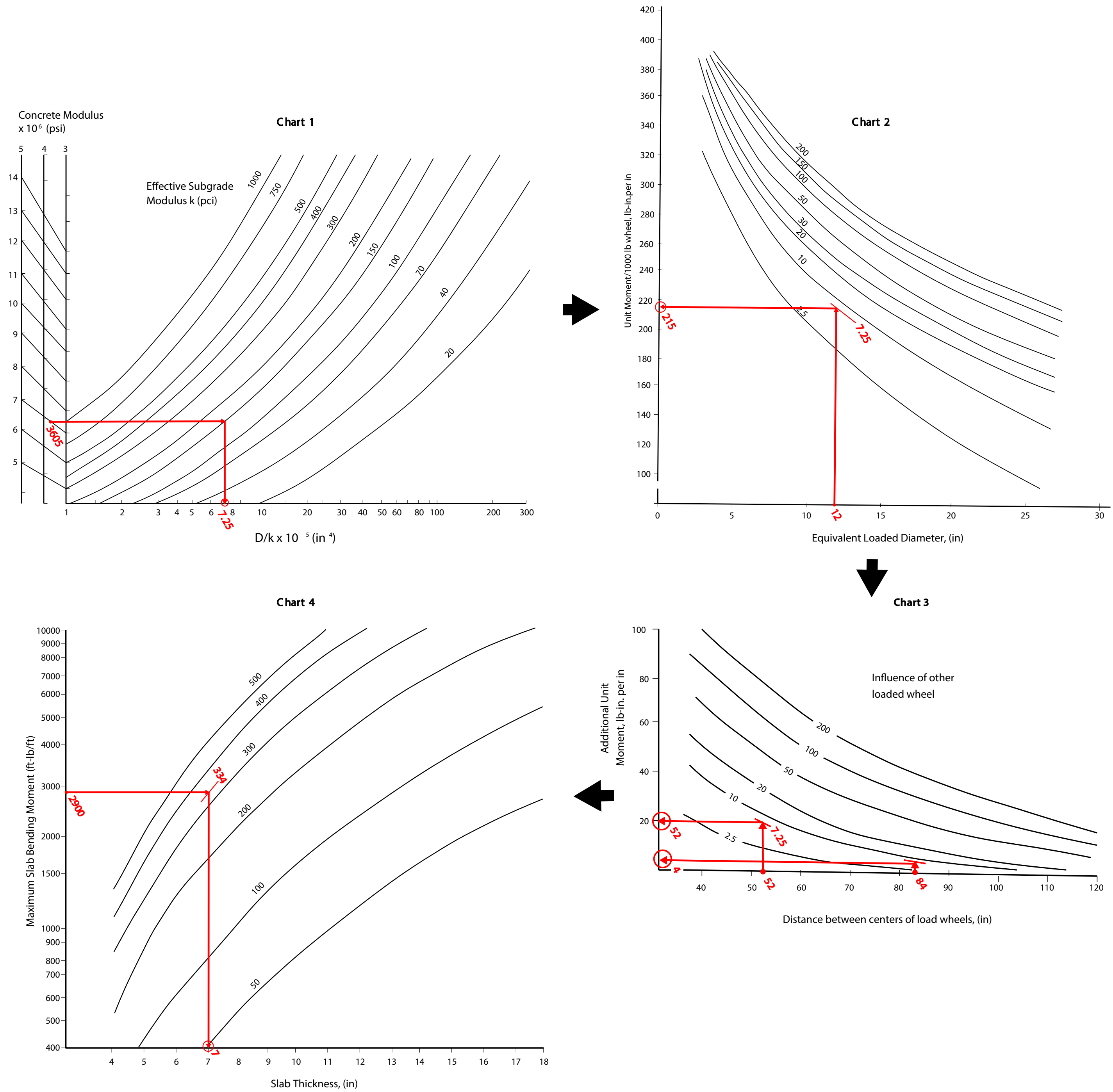

Figure 2. WRI method.

Both of these methods are based on limiting the tension on the bottom of the slab resulting from the applied wheel loads. The ACI guide offers design charts for both of these methods which call for similar inputs and yield similar results. A third method using Corps of Engineers' Charts is also suggested by the guide. This approach has a far broader scope in terms of accounting for cumulative passes by different kinds of trucks over the slab's life, but it is not developed to accommodate the precise inputs and the particular outputs this article aims to present.

The Concrete Truck

A typical fully loaded truck exerts 66,000 pounds on the slab, 28,000 pounds on each of its rear axles. An empty truck weighs 27,000 pounds. Each additional cubic yard of concrete adds 4,000 pounds. The distance between the front and rear axles is typically around 20 feet. The rear axles are separated by around 4.5 feet and, on each axle, wheels are separated by around 8.5 feet in plan view. The rear axles govern design, considering the share of load they carry and their proximity to each other. As will be shown in the design charts, the proximate wheels have a considerable effect on the slab's design. The typical tire pressure is 120 psi.

Slab-On-Grade and Soil Properties

On most industrial warehouses and distribution centers, 4,000 psi concrete is used for slabs. The slab thickness is 6 to 7 inches for smaller scale structures and 7 to 8 inches for larger ones. The crucial property is the modulus of rupture. The ACI design guide suggests using $9\sqrt{f_c}$ times a safety factor. Based on ACI-360 recommendations, a factor-of-safety of 1.7 has been used in the analysis. A

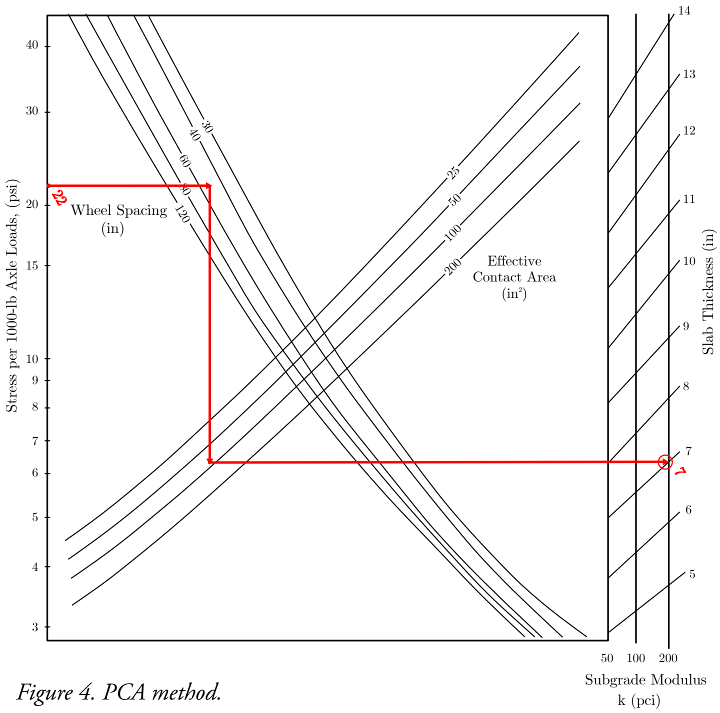

Figure 4. PCA method.

higher factor-of-safety of 2 may be utilized for additional assurance depending on the engineer's judgment.

Geotechnical recommendations typically include the value of the modulus of subgrade reaction. Soils that are highly compressible, and have low strength, have lower subgrade modulus (around 100pci) while moderately stronger soils have a higher design subgrade modulus (around 200pci).

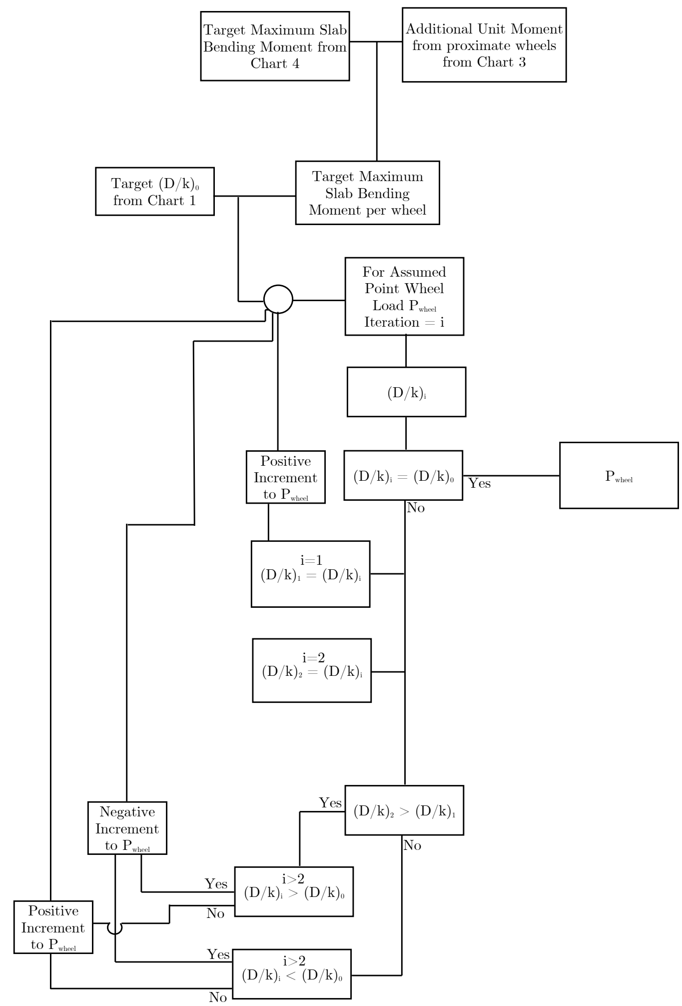

Figure 3. WRI method flowchart.

Design Methods

The WRI method goes through a series of design charts to estimate the design slab thickness for a given wheel load (*Figure 2, page 15*). These charts were used in the reverse direction for the purpose of this analysis. Instead of computing an allowable slab thickness for a target wheel load, the allowable wheel load for a given slab thickness and subgrade modulus needed to be calculated. The calculation is tricky as the process now becomes non-linear. One has to satisfy multiple conditions with the chosen inputs. The trick lies in beginning with the inputs that are not affected by the output, and eliminating them. Refer to *Figure 3* for the algorithm.

The PCA method simplifies the process, using only one design chart. To estimate the slab thickness, this method uses rupture stress per 1,000 pounds of axle load, the wheel spacing, and the area of contact. It does not have an approach to account for the presence of a proximate heavy axle. An amplification factor on the axle load is used to ensure the inputs are consistent. This amplification factor can be the same as the ratio of the additional unit moment to unit moment obtained from WRI.

Results

A consistent safety factor has been used for both methods. The *Table* presents a summary of the results for typical slab thicknesses and subgrade moduli. The result in question is the amount of off-loading necessary for a typical truck. It can be seen that both methods yield comparable results for the given inputs. An 8-inch thick slab is almost always fine for a fully loaded concrete truck. A 7-inch slab can allow for around 60 to 80% of a full truck, whereas a 6-inch thick slab can only allow for 25 to 35% of a full truck.

Conclusions

Driving concrete trucks on slabs should not be the contractor's first choice but rather considered with great caution after all other options are exhausted. While the study relies on values of modulus of subgrade reaction, certified pads may have soft spots. If it happens that trucks drive over those spots, the slab will be damaged. In the authors' experience, some of this damage may not appear for years after construction. Additionally, possible slab surface damage from rocks, mud, and debris, should be considered and planned for before allowing trucks to go on the slab.■

Table showing change per truck.

				Change in Cubic Yards of Concrete per Truck								
				Slab Thickness = 6in			Slab Thickness = 7in			Slab Thickness = 8in		
	Factor of Safety			Subgrade Modulus (k)								
Method	*ACI 360R-10*	*Ringo & Anderson*	Used	100 (pci)	150 (pci)	200 (pci)	100 (pci)	150 (pci)	200 (pci)	100 (pci)	150 (pci)	200 (pci)
WRI	*2*	*3*	1.7	-7.0	-6.7	-6.4	-4.1	-2.6	-1.7	-0.3	FULL	FULL
PCA	*1.7*	*2*	1.7	-7.3	-6.7	-6.1	-3.5	-2.3	-1.5	-0.6	FULL	FULL
Average				-7.1	-6.7	-6.3	-3.8	-2.5	-1.6	-0.4	FULL	FULL
Average (% Full Truck)				26%	30%	35%	61%	74%	83%	95%	FULL	FULL